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DEGREE IN MARINE BIOLOGY AND FISHERIES

Characterization of zooplankton communities associated with an anticyclonic Eddy, in the northeast of the islands of Cabo Verde

Internship Report of Course Degree in Marine Biology and Fisheries

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TITLE: "Characterization of zooplankton communities associated with a eddy anticyclonic, in the northeast of the Cabo Verde archipelago"

KEYWORDS: Eddy; zooplankton; oxygen minimum zone; migration; Cabo Verde.

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MINDELO

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The contents of this report are the sole responsibility of the author:

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/Miryam Edvam Lima/

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ABSTRAT

The Zooplankton is represented by bodies of virtually all groups of marine invertebrates and some vertebrates. A large part of them perform daily vertical migrations, where the greater zooplankton concentrations are found in deeper layers of the ocean during the day and on the surface with the overnight. Zooplankton is characterized by having a limited locomotion, and may therefore be imprisoned in bodies of water, such as the eddy. These eddies are rotating closed streams of thermal characteristics different from in the external environment. Their impacts on the marine ecosystem may be several, including inhibition of vertical migration of zooplankton and nekton, heavy losses of nitrogen and oxygen concentrations decrease of seawater.

Recently, isolated bodies of water with low oxygen content have been identified near the Cabo Verde archipelago in the Atlantic tropical Northeast. In this context, this study was carried out with the primary objective to study the possible impacts that an anticyclonic eddy may result in marine ecosystems, emphasizing the zooplankton communities. To enforce this objective, during the month of March 2014 was sampled at various points of an eddy and in the oceanographic Observatory of the Cabo Verde. The sampling included the record of temperature, salinity, oxygen and fluorescence (chlorophyll), the collection of water samples (for the determination of dissolved nutrients) and zooplankton. The results showed a minimum oxygen zone, at the core of the eddy, located about from 85 to 120 m depth. The concentration of zooplankton in this layer was low due to the hypoxic conditions, incompatible the survival of many organisms in this area. However, in the Centre of the eddy the abundance of zooplankton was greater than in this margin, as well as in relation to the Observatory. This may be explained by the upwelling which carries large concentrations of nutrients, and also for the conservation of the physico-chemical properties of the water, which favored the survival of organisms, noting greater abundance of some taxa in the oxygen minimum zone.

Keywords: Eddy; zooplankton; oxygen minimum zone; migration; Cabo Verde.

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1- INTRODUCTION

In aquatic environments we can find a great diversity of organisms, both microscopic and macroscopic (Barnes & Ruppert, 1993). Within this diversity are pelagic organisms, comprising the nekton and plankton (Barjau, 2006; Ré, 2000). The nekton consists of animals that actively move in the water column, therefore overcoming the force of the currents, and plankton of organisms that do not possess movements strong enough to overcome the currents of the water column where they live (Ré, 2000).

Planktonic organisms can be classified according to their dimensions, vertical distribution, nutrition, planktonic lifespan and biotope. Although these different classification criteria are artificial, they are important for the systematization of the various categories that constitute the plankton (Ré, 2000). As to the mode of nutrition, they can be classified into phytoplankton (autotrophs), zooplankton (heterotrophic beings) and mixotrophs that are both autotroph and heterotroph (Ré, 2000). Phytoplankton is composed of a large number microscopic algae and bacteria whereas zooplankton is formed basically by representatives of all groups of marine invertebrates (Barnes & Ruppert, 1993), mainly including appendicularia, cladocera, copepods, chaetognaths, jellyfish, molluscs, salps, ostracods, among others (CETESB, 2000).

The zooplankton organisms are indispensable for the maintenance of the aquatic ecosystem, as they are an important link in the food chain (Pacievitch, 2010). Also, they have an important role in channeling energy from primary producers to the consumers of higher trophic levels, and in acting as biological indicators (Pacievitch, 2010; Gonzaga, 2009), besides promoting vertical transport of organic matter and regeneration of nutrients (Meirinho, s.d.; Gonzaga, 2009).

The zooplankton consists of very diverse organisms with highly variable sizes and limited mobility (Gonzaga, 2009). According to body size we can classify them into nanozooplankton with 2-20µm (nanoflagellates), microzooplankton with 20-200µm (foraminifera, rotifers, small copepods, crustacean nauplii), mesozooplankton with 200-2000µm (larger copepods, appendicularia adults, chaetognaths, ctenophores), macrozooplankton with 2-20mm (hydromedusae, siphonophores, copepods, euphausiids, fish larvae) and megazooplankton with more than 20mm, which includes the siphonophores, thaliacea, among others (Gonzaga, 2009).

Differents taxa of zooplankton display distinct distribution patterns under the influence of physical, chemical and biological (Christiansen, 2013) factors. The extent of migration and shape of the vertical distribution of the population can be strongly influenced by the variation of the light intensity (photoperiod), the sea water temperature, pressure, gravitational attraction, season, nutrient concentration, phytoplankton density, the thermocline depth and structure, primary production, oxygen concentration in the layers of water and food availability (CETESB, 2000; Christiansen, 2013; Ré, 2000).

A substantial part of zooplanktonic organisms performs diurnal vertical migrations (DVMs) in the water column according to the day/night switching (CETESB, 2000) such thatduring the day there are greater concentrations of zooplankton in deeper layers of the ocean and overnight they migrate to the surface (Christiansen, 2013). It is believed that possibly this happens to prevent ultraviolet radiation, escape from predators that use sight for hunting and, in addition, saving energy by performing metabolic suppression in cold waters (Christiansen, 2013; Lampert, 1989). These migrations may differ from species to species and between different ontogenetic stages of same species (Lampert, 1989).

Although DVMs bring many advantages, they also entail several disadvantages to zooplanktons, such as permanence in environments where the temperature gradients are variable, in which food availability is less, spending more energy to swim and the metabolic processes are delayed, which leads to consequences in growth and reproduction (Christiansen, 2013).

Since the zooplanktonic organisms are animals with limited mobility, they can be entrapped into water bodies, often as part of a closed ecosystem such as an eddy. Eddies are circulating flows of different thermal characteristics than the surrounding environment, with cyclonic or anticyclonic whirls (Oliveira, 2009; Oliveira, 2010). Cyclonic eddies (cold core) are those that have sense of rotation in the southern hemisphere and counter clockwise in the northern hemisphere since the anticyclone (warm-core) are those who have a sense of anti-clockwise rotation in the southern hemisphere and clockwise in the northern hemisphere (Pilo, 2013).

Eddies promote a closed stream, its borders are limited by gradients of physical properties in the surface and subsurface (Omachi, Pereira; Samson, 2009). These enclosed bodies of water can form due to baroclinic or barotropic instable situations and also due to topography or existing currents in continental slopes (Pires, 2008; Lima, 2011). These eddies promote energy exchanges with medium flow, transportation and mixture of temperatures and salinity, mixture of the surface layer of the oceans, distribution of trapped water, in addition to holding most of the kinetic energy of the ocean (Pilo, 2013; Oliveira, 2010).

Their impact on the marine ecosystem may be several, in particular inhibiting the vertical migration of zooplankton and nekton, leading to great losses of nitrogen from sea water (Fiedler *et al.*, s.d.), increasing the primary production in a region, lead to an increase in local fishing production and causing major impacts on the global carbon cycle (Stramma, Johnson, Sprintall, & Mohrholz, 2008).

Moreover, by having a closed stream their oxygen concentrations decrease gradually, reaching minimum values (with concentrations below 60 to 120 µmol kg^{-1}), as will be demonstrated in this paper. These hypoxic bodies of water might lead to death of living beings trapped in eddies, therefore potentially affecting the management of fishery resources (Stramma *et al.*, 2008).

Asymmetric structures of rotating circulation were recently detected in the waters of Cape Verde, resulting from complex hydrodynamic effects supplied by bodies of water coming from the Canary that reach our archipelago (Medina, 2008). According to the same authors, these structures are associated with bio-oceanographic processes, upwelling phenomena and biological material flow.

Since then, several eddies have been monitored, through satellites, glider and oceanographic expeditions, through which, isolated bodies of water with low oxygen content were discovered recently near the archipelago (Fiedler *et al.*, s.d.), in the Eastern Tropical North Atlantic (Karstensen *et al.*, 2012). These bodies of water were classified as mesoscale eddies or oceanic phenomena with ranges of 50-500 miles into space and 10-100 days in time (Schütte, 2013). They originated from the coast of Mauritania upwelling and propagate Westward (Fiedler *et al.*, s.d.).

Although they may represent a threat to the ecosystem, since organisms avoid or can't adapt to oxygen concentrations below 40 µmol.kg^{-1} (Karstensen *et al.*, 2012), until now, no studies of the biological communities associated with these water masses in Cabo Verde, existing only autonomous observations of the same physical and chemical characteristics (Fiedler *et al.*, s.d.).

Thus, in the present study, in addition to the analysis of the physical and chemical features, was also studied the zooplankton community structure in different periods of the day, in a Eddy identified northeast of the Cabo Verde archipelago, during the month of March of the current year.

2-OBJECTIVES

2.1- General objective:

The aim of this work is to study the impact of an anticyclonic mode water eddy (ACME) on the marine ecosystem, focusing on the zooplankton communities.

2.2- Specifics objectives:

- ✓ Determine the hydrographic features (in particular the concentration of oxygen) in the water column;
- ✓ Identify the oxygen minimum zone in an ACME in Cabo Verde;
- ✓ Classify and quantify the zooplankton associated with a eddy and an external point, using a plankton profiler by video techniques (Under Vision Profiler-UVP) and a multinet (Hydrobios), in order to analyse the impact that this eddy has on the zooplankton communities;

3- MATERIALS AND METHODS

3.1- Area of study

Cabo Verde (figure 1.a) is composed of ten islands and five main islets of volcanic origin, for approximately 600 Miles off the Western African coast, off the coast of Senegal, to 1350 nautical miles east of Brasil and 2750 miles southwest of Great Britain. The Cabo Verde archipelago is located between a latitude of 14° 48 ' to 17° 12 ' North and a longitude of 22° 44 ' to 25° 22 ' West (Ministério do Ambiente Agricultura e Pescas, 2004).

It belongs to the eco-bio-geographical province North Atlantic Tropical Gyral Province (NATR), bathed by the waters of the Canary cold current and under the influence of seasonal variations of the North Equatorial Current (NEC) and the North equatorial current (NECC), affecting the surface circulation of the archipelago (Lazaro *et al*., 2005; figure 1.b).

According to Stramma *et al*. (2005), Cabo Verde is influenced by two bodies of water (figure 1.b), the north central Atlantic (North Atlantic Central Water-NACW) and the central South Atlantic (South Atlantic Central Water-SACW).

Although the NACW is hotter than the SACW, the two water bodies occupy the same density range (Stramma, Huttl, & Schafstall, 2005). The SACW is where originates the upwelling, with lower salinity and higher level of nutrients compared to the NACW (Fiedler, 2012).

The border between these two bodies of water is called a Cabo Verde Frontal Zone (CVFZ), located at 20° N from Africa and 16 ºN from the Tropical Central Atlantic. It is a quite unstable area and generates Mesoscale variability (Vangriesheim, Bournot-Marec & Fontan, 2003), working as a barrier between the inner ventilated area of the North Atlantic subtropical gyre and the shadow zone with low oxygen level (Stramma *et al.,* 2005).

In addition, it is assumed that part of the coastal upwelling system situated on the coast of Mauritania reaches the waters of Cabo Verde leading to an increase in primary production (Almada, 1993), since this upwelling brings cold waters rich in nutrients from the deeper layers of the ocean, promoting an area of high biological productivity (Schütte, 2013).

The surface temperature of ocean waters that bathe the archipelago is very stratified in the first 100 m. The depth of the layer blending varies between 25 to 40 m, with an average temperature of 25ºC; from it a thermocline with temperature 0.1° C/m up to 100 m depth can be found (Marques *et al*., 1997).

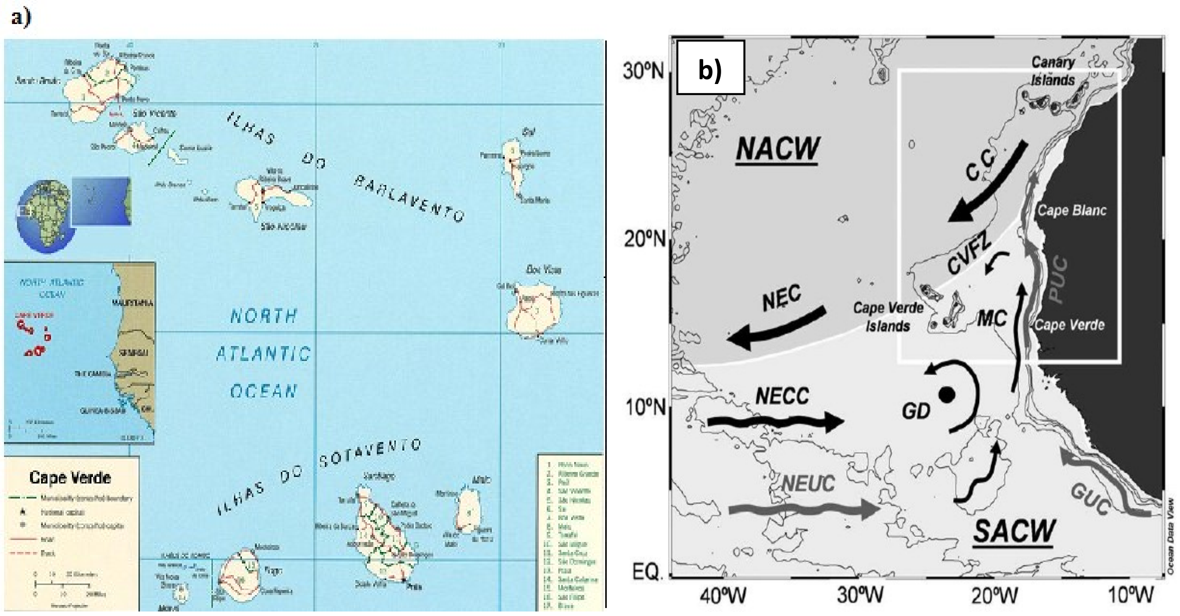

Figure 1: a) Location of the Cabo Verde archipelago 600 miles of the West coast of Africa. b) Schematic of the circulation pattern showing the main current and dynamic characteristics: Canary Current (CC), North Equatorial Current (NEC) and the North Equatorial counter current (NECC), North Equatorial Undercurrent (NEUC), Mauritania Current (MC), the Guinea Undercurrent (GUC), and Cabo Verde Frontal Zone (CVFZ). Extracted respectively of Bacelar, (2004) e Peña-Izquierdo *et al*. (2012).

3.2- Sampling

Samples for the realization of the present study (Table 1) were collected during the day and also at night, during two cruises, one aboard the oceanographic vessel Islândia (annex A), of the INDP (Instituto Nacional de Desenvolvimento das Pescas) and another aboard the oceanographic vessel Meteor (annex A), of the GEOMAR (Instituto Helmholz Centre for Ocean Research Kiel), in beginning and middle of the month of March 2014, respectively. In these two cruises, samples were collected in the eddy, in different geographic locations (Figure 2).

Table 1: Samples taken by ships Inslândia and Meteor in the Eddy, in March 2014.

Ship	Cruise	Instrument	Material	Location
Meteor	M105	CTD	Water samples	Towards margin
				Towards margin
				Towards margin
				Towards margin
				Core
				Towards margin
				Margin
				CVOO
		Multinet	Zooplankton samples (see Annex E)	Core
				Core
				Margin
				CVOO
				CVOO
Islândia	ISL00314	CTD	Water samples	Towards margin
				Towards margin
				Towards margin
				Towards margin
				Towards margin
				Towards margin

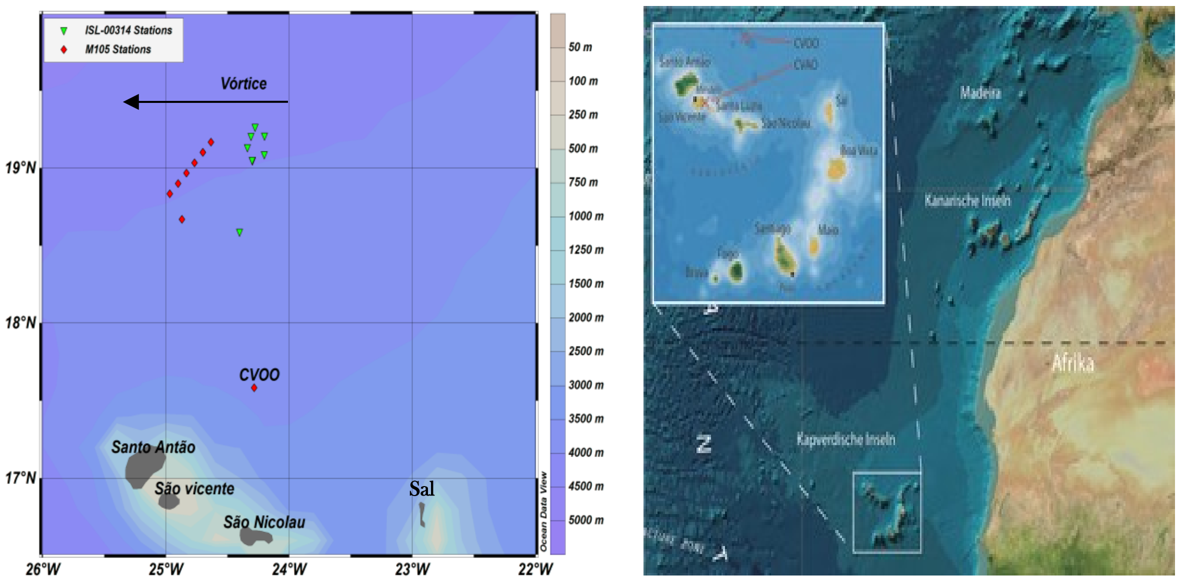

Figure 2: Map of CTD launched around the eddy by ship Islândia and the ship Meteor northeast of the islands of Cabo Verde, in different geographic locations, in the month of March. Oceanographic Observatory of Cabo Verde (CVOO), located at 17.6° N 24.3° W. Fonte: Schlitzer (2013) e http://cvoo.geomar.de/index.php?id=23.

3.2.1- Sampling with the CTD

CTD (Conductivity Temperature Depth; &, annex B) is a profiler that allows knowing the physical properties of the water column at a given point, from the surface to the depth of anchoring. Sampling was carried out with the help of vertical profiles CTD SBE 19 plus SECAT Profiler, coupled to a dissolved O_2 sensor (SBE43), a radiation sensor PAR (photosynthetic active radiation) and a rosette with 24 Niskin bottles of 12 liters each. The instrument was inserted in the water column by an oceanographic winch, and as it was lowered, data such as temperature, salinity, oxygen, turbidity and fluorescence of the water column were directly sent to a computer by means of an electromechanical-conductor cable. These data were archived in hex format through software provided by the manufacturer of the device. For the reading of the data, these were converted to format CNV by the program SBEData Processing Win32 and converted in MS® Office Excel sheets.

The rosette collected water samples in the depths of 450, 350, 250, 150, 100, 80, 60, 40, 20 and 10 m, having been doubled sampling depths 450 and 10 m. After the arrival of the instrument on deck, subsamples were collected to determine nutrients in adequate and properly labeled jars. Samples for the determination of dissolved nutrients were collected in polyethylene bottles of 0.5 l and properly preserved.

Finally, the samples were transported to the laboratory where they were analyzed.

3.2.2- Zooplankton sampling with MSN (Multi Sampler Net)

MultiNet (annex A) is a device that is used for vertically stratified sampling of zooplankton, equipped with 5 or more plankton nets which collect samples sequentially at different depths (hydrobios, s.d.). It consists of a control unit electrically powered by a stainless steel structure that has a part with 5 (or 9) network bags with zippers, which are opened and closed by a lever system, controlled by the control unit and has a part in the end of the networks called the cod end (hydrobios, s.d.).

The samples were collected during the day and during the night, in order to analyze the daily variation in the concentration of zooplankton. The appliance is inserted into the water and the collection of samples (with size exceeding 200 µm) was made in the intervals of 600-300 m (net 1), 300-200 m (net 2), 200-120 m (net 3), 120-85 m (net 4) and 85-0 m (net 5) deep, previously defined depending on the oxygen profile within the eddy. However, since the CVOO sampling also represented the monthly timeseries sampling, the depth steps here were 1000-600m, 600-300m, 300-200m, 200-100m and 100-0m. Subsequently, each sample was rinsed onto a 100µm mesh, and from this transferred to a previously labeled Kautex bottle. Then seawater and 10 ml of 37% formaldehyde were added to the bottle, obtaining a final concentration of 4% formaldehyde. This procedure was repeated with all samples collected (annex F), which after the end of the cruise were transported to the lab.

In the laboratory, the samples were washed; pouring each into a 64 µm sieve, and rinsed with filtered seawater (35 psu salinity) in order to remove all formaldehyde. Next, each sample was transferred to a 1000 µm sieve, collecting the large fraction (organisms larger than 1000 µm) and the remaining sample was placed again in the bottle for later separation of medium and small fractions. The same procedure was repeated with the medium fractions (body sizes between more than 500 µm and smaller than 1000 µm) and small fractions (organism sizes greater than 200 µm and less than 500 µm), for the same sample.

Each fraction was transferred to the scanner's digitalization chamber (scan Hardware EPSON PERFECTION V750 PRO) (see annex B), and this was supplemented with filtered seawater. After that, the individual particles were separated manually with tweezers and a needle. The images obtained by the scanner were properly stored, and after that the protocol was filled up (see annex D e C). In cases where the concentration of individuals in a sample was too large, the sample was divided in sub-samples, with the aid of the splitter Motoda Plankton Splitter, thus facilitating the handling of the sample in the scanner and reducing the number of objects to be sorted. Finally, the whole sample was transferred to the original Kautex bottle and thouroughly preserved in 4% formaldehyde.

The saved images were processed using the Zooprocess image analysis software (Picheral, 2003), in which the final result were vignettes (a single image), accompanied by information such as size, dimension, area, length, width, among others. Then, these vignettes were automatically grouped into folders (prediction), according to the category and with the fraction, using the Plankton Identifier (Gasparini & Antajan, 2007-2013). Finally, the classification (annex E) was manually validated using the Xnview image application (Xnsoft, 2014).

3.2.3- Sampling zooplankton with the UVP

The plankton profiler by video techniques (Under Vision Profiler-UVP; annex B) is a suitable device for the quantitative study of vertical distribution of zooplankton with size greater than 500 µm and particles with size greater than 60 µm. The latest model, UVP5, is an underwater imaging system, compact, weighs only 30 Kg, and can act as a stand-alone instrument or attached to a CTD (Picheral, Guidi, Stemmann, Karl, Iddaoud, & Gorsky, 2010).

This appliance is equipped with a 1.3 megapixel camera, using a computerized optical technology, with custom lighting and acquires digital images of zooplankton *in situ*, until the depth of 6000 m (Picheral et al., 2010). The UVP acquires only images in focus, in a volume of water bordered by a light beam emitted from light-emitting diodes (LEDs) in 100 μ s flashes.

In all the sampling performed with ship Meteor, the profiler was released coupled with a CTD, until the depth of 6000 m, and with the ship Islândia were released separately. As it descended (1 $m.s^{-1}$) it took between 3 and 11 pictures per second of the particles present in the water column, these images were sent to an onboard computer, for further analysis. The images are automatically stored and separated into individual images for each particle with size greater than 500 μm. Once in the lab, these were processed using the Zooprocess imaging software (Picheral, 2003) and grouped automatically in the main categories using Plankton Identifier (Gasparini & Antajan, 2007-2013). Finally, this prediction was validated manually, using the Xnview image application (Xnsoft, 2014).

3.3- Laboratory Analysis

3.3.1- Determination of dissolved nutrients

These dissolved nutrients were analyzed using the automatic analyzer SEAL Analytical QuAAtro (annex B). The basic system consists of a computer (which manages all the process and where the data is automatically saved), a peristaltic pump, a collector of chemistry, a detector, and a data acquisition software, the AACE. The samples and reagents are pumped continuously through chemical tubes.

Automatic Analyzer SEAL Analytical QuAAtro is a modern instrument, with a continuous flow, used in industrial laboratories to carry out complex chemical reactions automatically, thus saving time and reagents.

It provided the concentrations of nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{-3}) and silicate (SiO_2), as well as the efficiency in the reduction of nitrate to nitrite.

At the end of each measurement, the files of results produced by the equipment were converted into MS® Office Excel sheets.

3.4- Data treatment

All results were grouped into Excel spreadsheets, which used the data recorded by the CTD for vertical profiles of temperature, salinity, chlorophyll and oxygen along the water column, for CVOO, core and margin of the eddy. The data from the sampling with the UVP and the data provided by CTD and by laboratory analysis of samples of nutrients and dissolved oxygen were imported into Ocean Data View (Schlitzer, 2013), where the graphs of temperature, salinity, dissolved oxygen, nutrients and chlorophyll were made.

The ODV is a program of exploration and interactive graphical display of georeferenced oceanographic data, profile or time series. Vertical profiles of chlorophyll, temperature, salinity, dissolved oxygen and nutrients, were made for the purpose of viewing the profile of variables in eddy. With the aid of ODV, vertical plots and sections were made for all variables, up to 600 m deep.

In the Multinet data, from the count of samples (i.e., the images in each folder), the abundance (number of individuals by m^{-3}) was calculated, as well as biomass (mg m^{-3}) and the volume occupied by individuals in each sample. Zooplankton abundance data were imported into R (R Core Team, 2014) where the graphics of zooplankton were built. R is a language and environment for statistical computing and graphics building, which is open and free. This program is considered a variant of the S language, which allows the user to access or change existing functionality, as well as create new features to respond to their specific problems more effectively. The interaction with the user is based on a command window and requires the use of programming.

4- Results

4.1- Physical-chemical properties of the eddy

From the data recorded by the CTD (salinity, temperature, chlorophyll and oxygen), it might be said that inside the Eddy, the salinity (Figure 3.a) ranged around 35 to 36, with the highest values were observed from the surface layer to 85 m depth. The temperature (Figure 3.b), from the surface to 300 m depth, varied from 15 to 20°C. The values of chlorophyll (Figure 3.c) reached the value of 2 mg/l up to approximately 60 m, below this depth these declined to very low values. Within the Eddy the oxygen values were found (Figure 3.d) very low, up to 10 µmol/kg at a depth of 100 m.

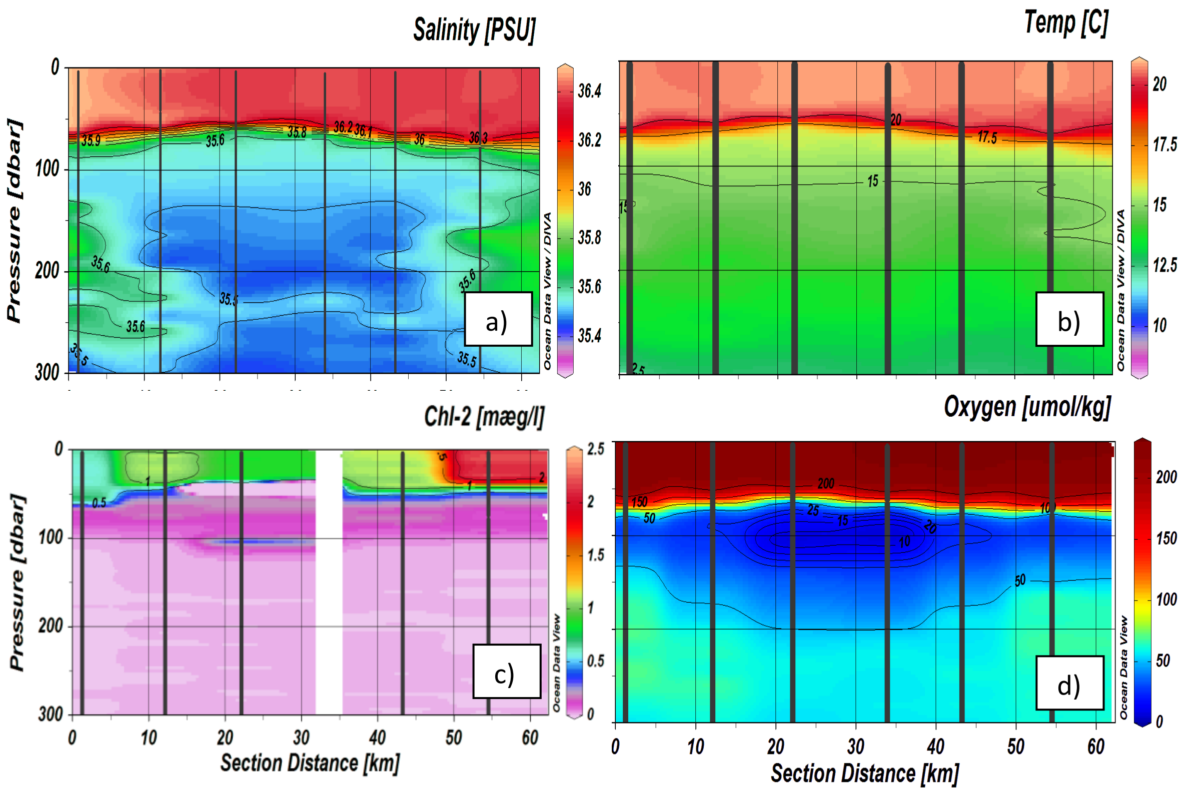

Figure 3: Physical and chemical properties in a section along the Eddy until 300 m depth, the core towards the margin, in mid of March 2014, sampled by the vessel Meteor. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013). a) Salinity, b) temperature, c) chlorophyll and d) oxygen. Dark vertical lines correspond to the points of release of CTD.

At the core of the Eddy, the gradients of temperature and salinity (0.16°C/m; 0.028 respectively) were relatively superior in respect of margin (0.08°C/m; 0.011 respectively) and CVOO (0.07°C/m; 0.003 respectively). This suggests that in the core of the Eddy the gradients have been more sudden and more shallow mixing layer (Figure 4).

Close to 100 m depth, chlorophyll ranged from 0 to 1 mg/l and oxygen reached extremely low values. In addition, the oxygen gradient was higher in the core of the Eddy (6.47), showing a oxicline sharper, towards the core (Figure 5). The values of oxygen in the margin the Eddy were approximately 230 µmol/kg up to 100 m, and the same was found in CVOO. Below this depth was registered very low values (about 50 µmol/kg), on the edge of the Eddy.

It is also of note that in the area where the oxygen was minimal, at the core of the Eddy, the thermocline and halocline were more pronounced and more superficial, in relation to other points.

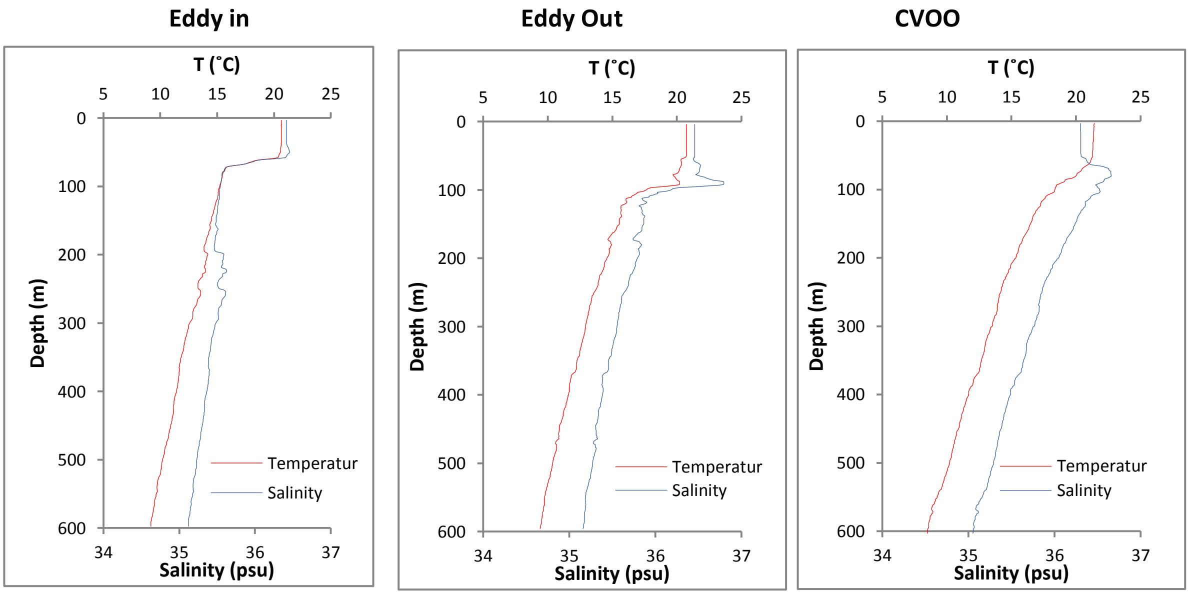

Figure 4: Vertical profiles of temperature and salinity concentrations, in the core and in the margin the Eddy and CVOO Observatory until 600 m depth sampled by the vessel Meteor, during the month of March 2014.

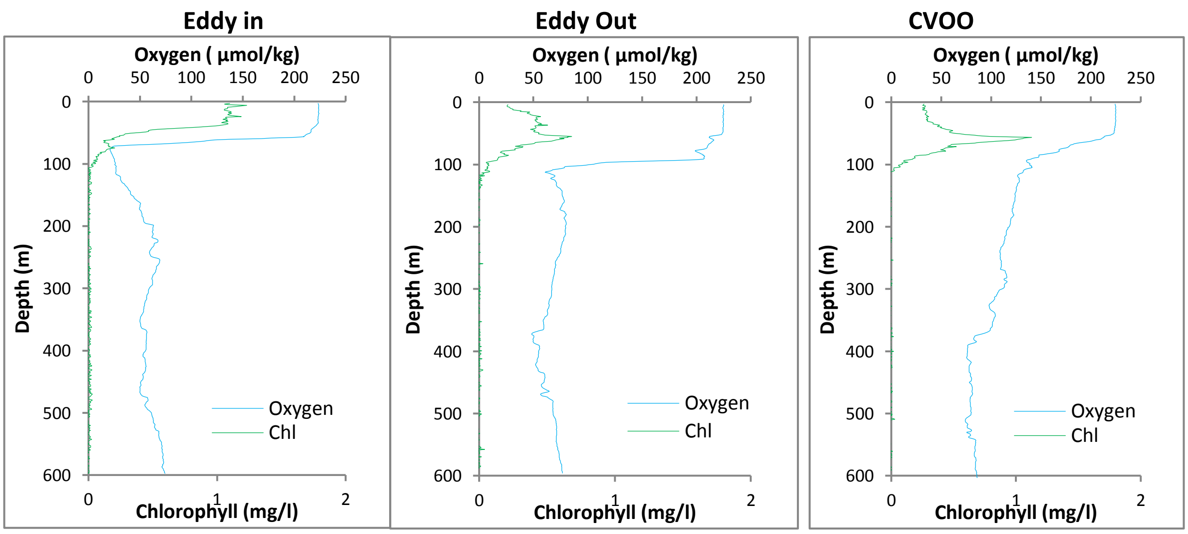

Figure 5: Vertical profiles of chlorophyll and oxygen concentrations, in the core and in the margin the Eddy and CVOO Observatory until 600 m depth sampled by the vessel Meteor, during the month of March 2014.

The data used in this study come from two cruises (ISL-00314 and M105), with sampling from different geographical locations. The results showed that the variables temperature (Figure 7.a), salinity (Figure 7.b), oxygen (Figure 7.c) and chlorophyll (Figure 7.d) recorded in mid of March had corroborated with the comments above. The temperature and salinity have remained similar in both samplings, made at the beginning (Figure 6) and in the middle (Figure 7) of the said month. However, oxygen and chlorophyll concentrations tended to decrease.

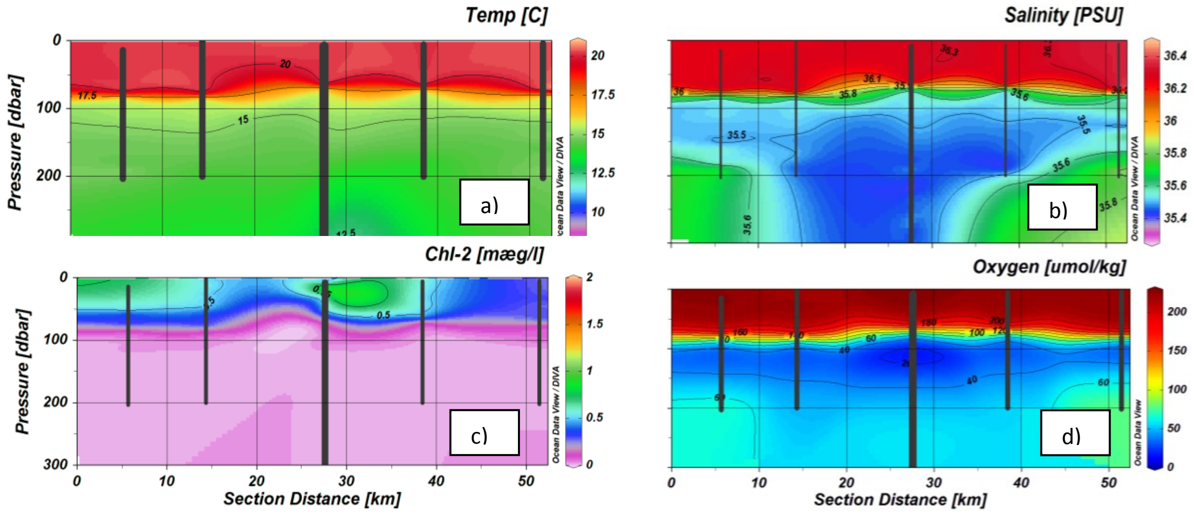

Figure 6: Physico-chemical properties in a section along the Eddy until 300 m depth, the core towards the margin, at the beginning of March 2014, sampled by ship Islândia. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013). a) Salinity, b) temperature, c) chlorophyll and d) oxygen. Dark vertical lines correspond to the points of release of CTD.

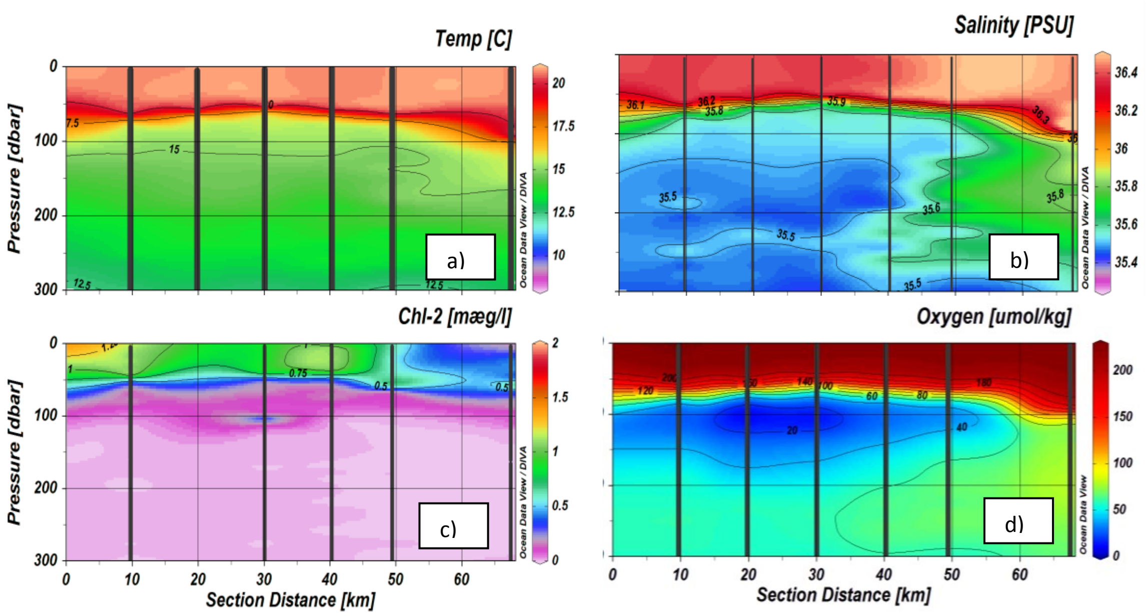

Figure 7: Physico-chemical properties in a section along the Eddy until 300 m depth, the core towards the margin, in mid of March 2014, sampled by the vessel Meteor. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013). a) Salinity, b) temperature, c) chlorophyll and d) oxygen. Dark vertical lines correspond to the points of release of CTD.

The analyses carried out in the laboratory included the determination of concentrations of nutrients in and out of the eddy. In that, inside the Eddy faced with concentrations of nutrients of 30 μmol/kg and approximately 22 μmol/kg. The concentrations of nitrite (NO_2-, see Figure 8) reached a maximum of 0.25 μmol/kg to 100 m depth and below that depth values decreased to values very close to zero, within the eddy. The largest concentrations found inside the Eddy were those of nitrate (NO_3-, about 30 μmol/kg, see Figure 8), followed by the silica (SiO2, approximately 15 μmol/kg, see Figure 9) and phosphate (PO_4^{-3}, about 2 μmol/kg, see Figure 9), from the surface to 500 m depth. The results of analysis of subsamples collected at the beginning of March it might be noted that concentrations of nutrients ranged from 0 to 32 μmol/kg and that collected in the mid of March ranged from 0 to 31 μmol/kg, revealing an increase in the concentration of nutrients over time. Nutrient concentrations were higher in oxygen minimum layer, having reached its peak in mid-March, except NO_2-, whose maximum concentration was recorded at the beginning of the month.

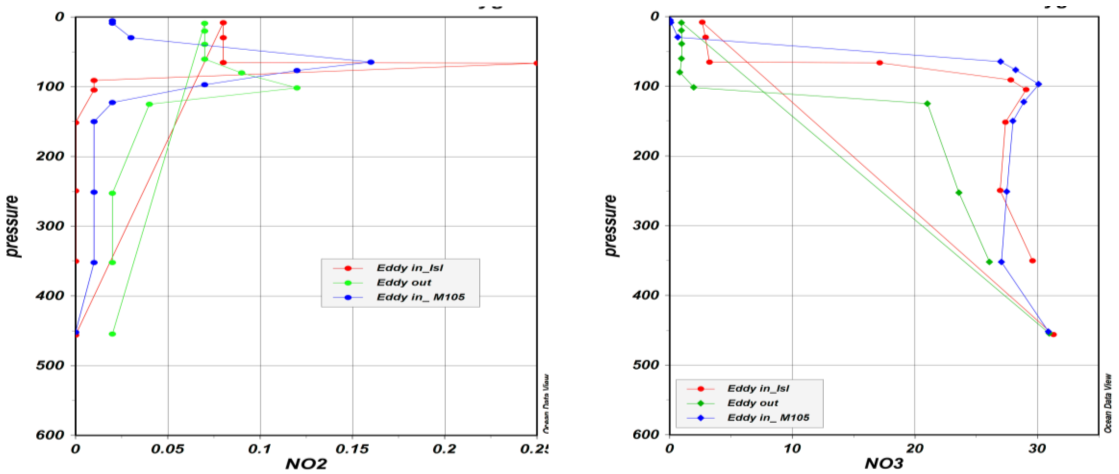

Figure 8: Vertical profiles of the concentration of nutrients (NO_2^- and NO_3^-), inside and outside the eddy, up to 600 m of depth sampled by boat Islândia and Meteor, during the month of March 2014. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013).

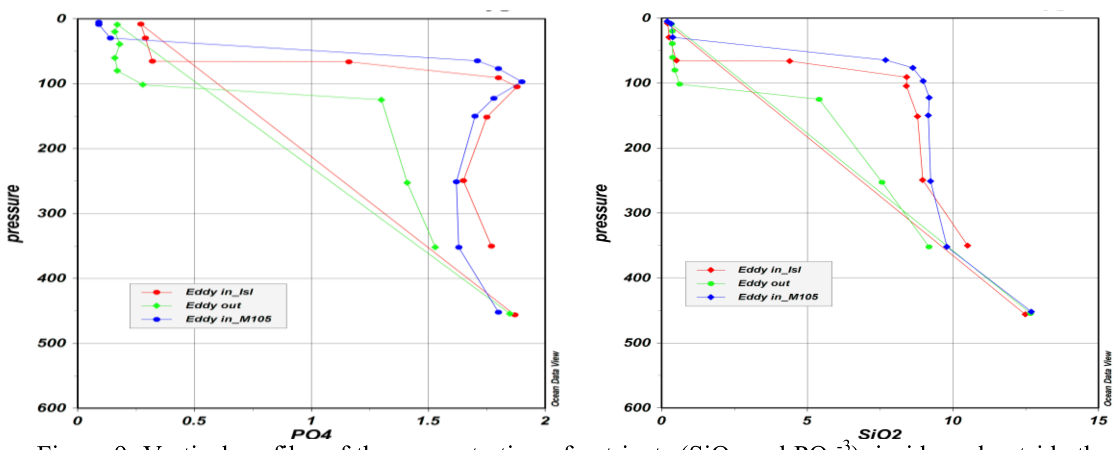

Figure 9: Vertical profiles of the concentration of nutrients (SiO_2 and PO_4^{-3}), inside and outside the eddy, up to 600 m of depth sampled by boat Islândia and Meteor, during the month of March 2014. Drawn up in accordance with the programOcean Data View (Schlitzer, 2013).

4.2- Abundance of Zooplankton

The concentrations of zooplankton collected with the aid of MultiNet inside the Eddy were far superior in respect of margin (Figure 10), suggesting greater productivity. In samples taken in the daytime, the concentration of zooplankton was greater near the surface with about 1500 organisms/m^3, tending to decrease under 100 m depth.

The data collected in three periods (nucleus and margin the Eddy and CVOO; Figure 10), showed that the core of the Eddy has about 3400 organisms/m^3, with approximately 1900 organisms/m^3 found at night and 1500 organisms/m^3 found in daylight. At the margin the Eddy, zooplankton concentration was approximately 700 organisms/m^3, however in the CVOO concentration was little more than 1400 organisms/m^3, having the same concentration in both periods of the day (about 712 organisms/m^3). At every point the concentration of individuals was higher in surface, up to 100 m depth, declining significantly below this layer.

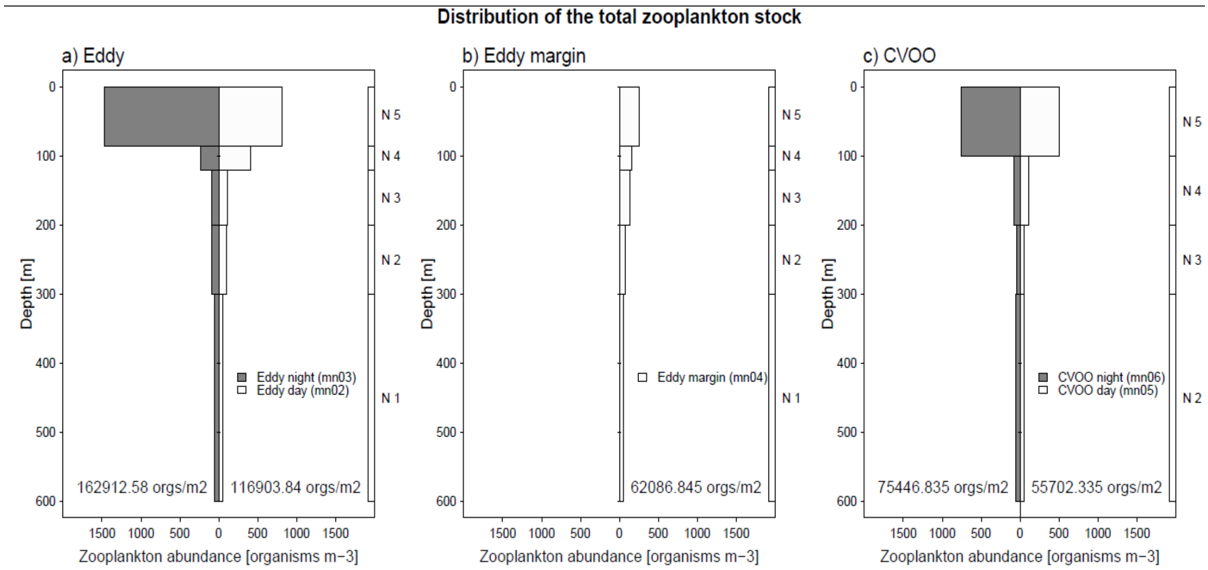

Figure 10: Abundance of zooplankton in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night sampled by the vessel Meteor, during the month of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

Taking into account that different zooplankton taxa have different distribution patterns, samples were subdivided into several groups, which it might be noted that in all they obtained more bodies inside the Eddy than in CVOO, with the exception of Euphauseacea, with a difference of a few individuals.

The most abundant group at the core of the Eddy were the copepods Calanoid (Figure 11) with approximately 1050 organisms/m^3 during night and 800 organisms/m^3 during daylight hours.

Also it should be noted that the copepods Eucalanid (Figure 12) had its greatest concentration in the core of the Eddy, during night, in relation to the CVOO. However, in the margin the Eddy could be observed greater abundance (about 15 organisms/m^3) of 150 to 300 m depth.

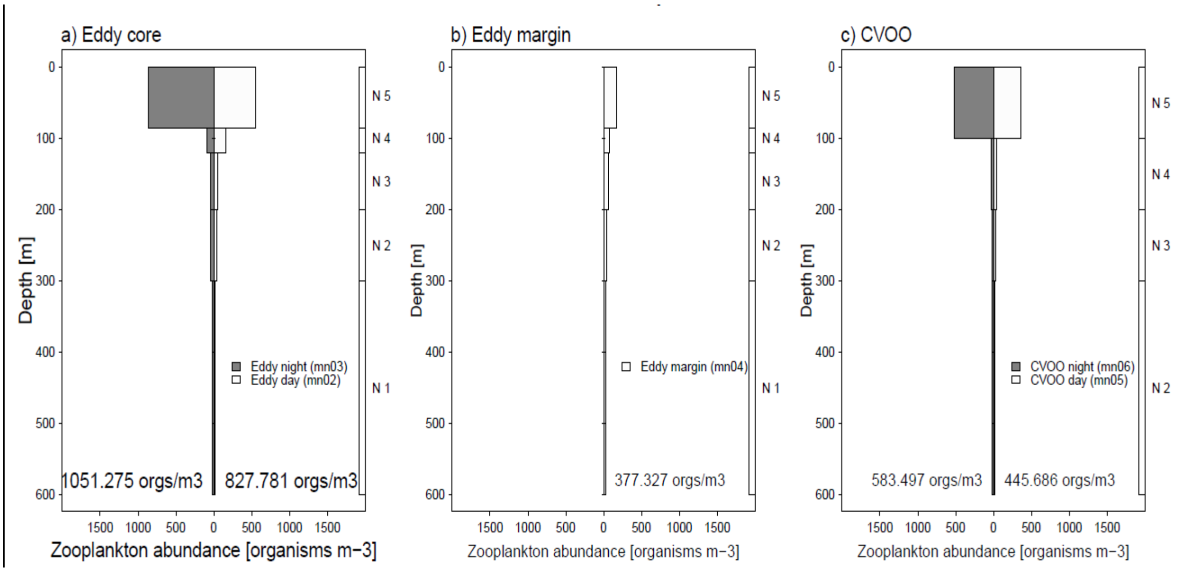

Figure 11: Abundance of Copepod Calanoid in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

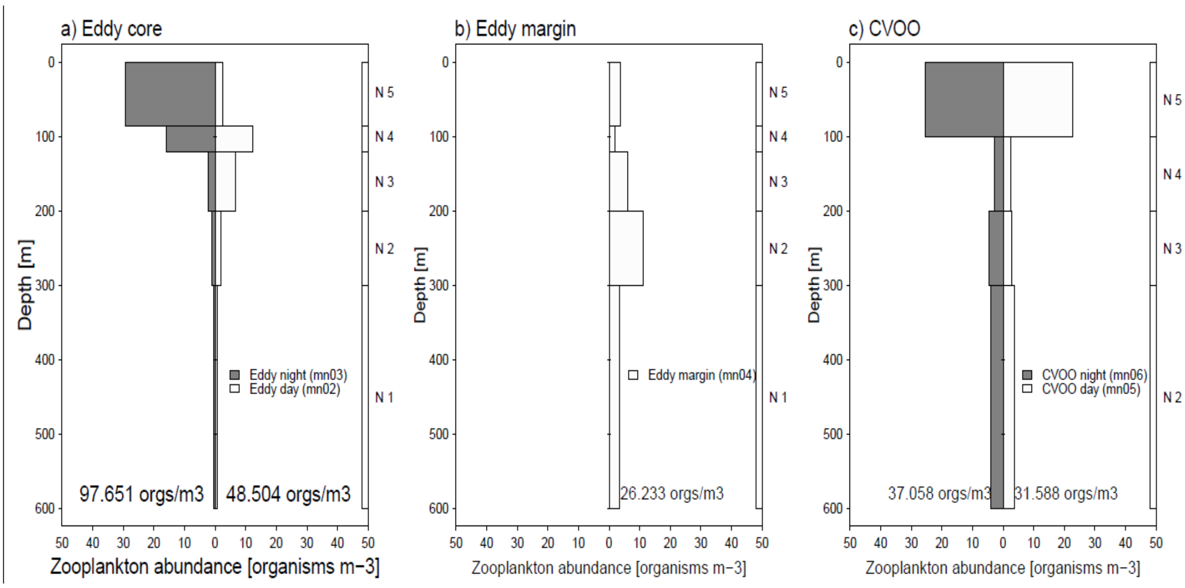

Figure 12: Abundance of Copepod Eucalanid in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014.. Drawn up in accordance with the program R (R Core Team, 2014).

During the day, the Macrosetella Group (Figure 13) had its greatest abundance of 100 to 150 m depth, in the core of the eddy. In copepods *Oithonid* (Figure 14) identified greater abundance in more superficial layers of the nucleus, however from 100 to 200 m, about 15 organisms/m^3 have been identified in the margin the eddy.

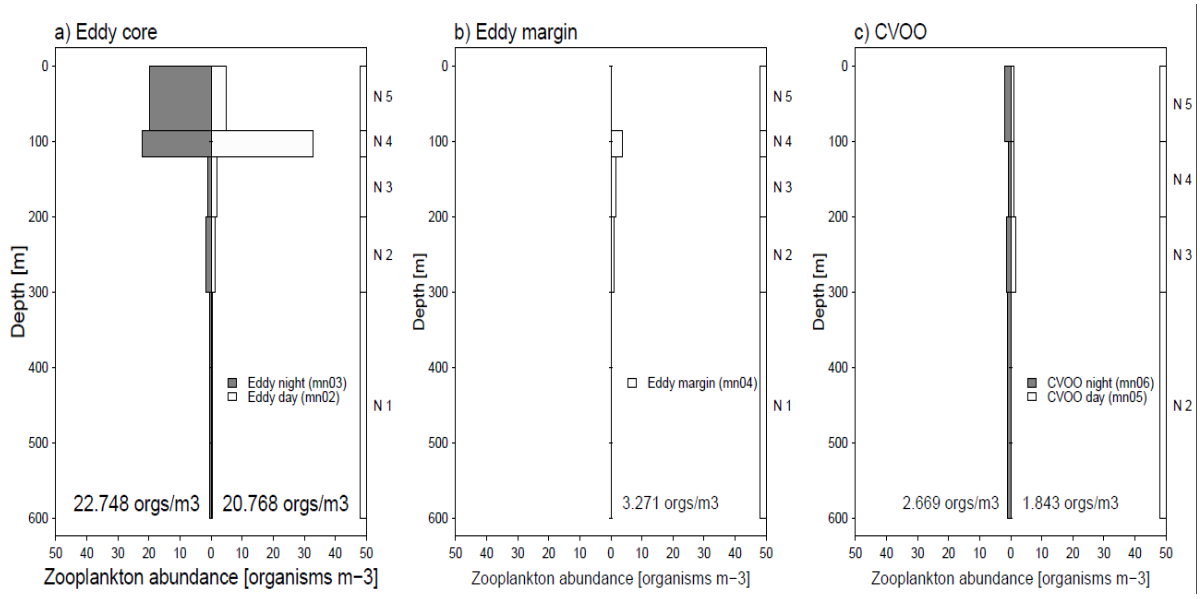

Figure 13: Abundance of Copepod Macrosetella in the core and in the margin the eddy and CVOO observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

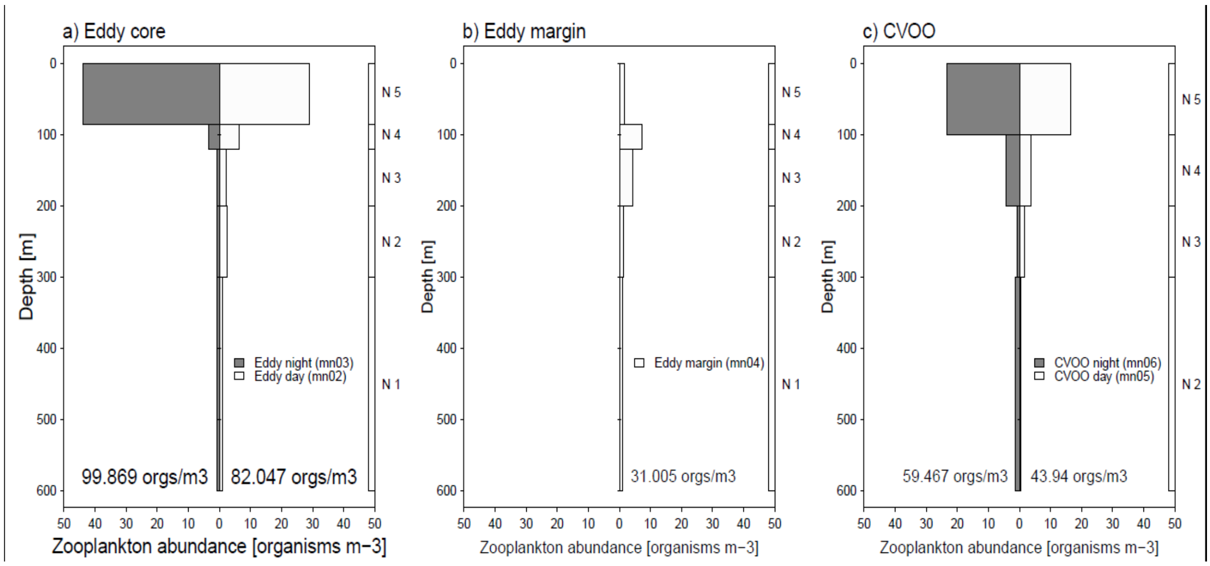

Figure 14: Abundance of Copepod *Oithonid* in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

The organisms belonging to the genus *Oncaeaid* (Figure 15) had their greatest abundance of 85 to 120 m depth, with approximately 13 organisms/m^3. The group with the lowest abundance was crustaceans Euphausiid (Figure 16) with about 2 organisms/m^3 during the night and 2 organisms/m^3 during the day, at the core of the Eddy and CVOO Observatory about 4 organisms/m^3 during the night and 1 body/m^3 during daylight hours.

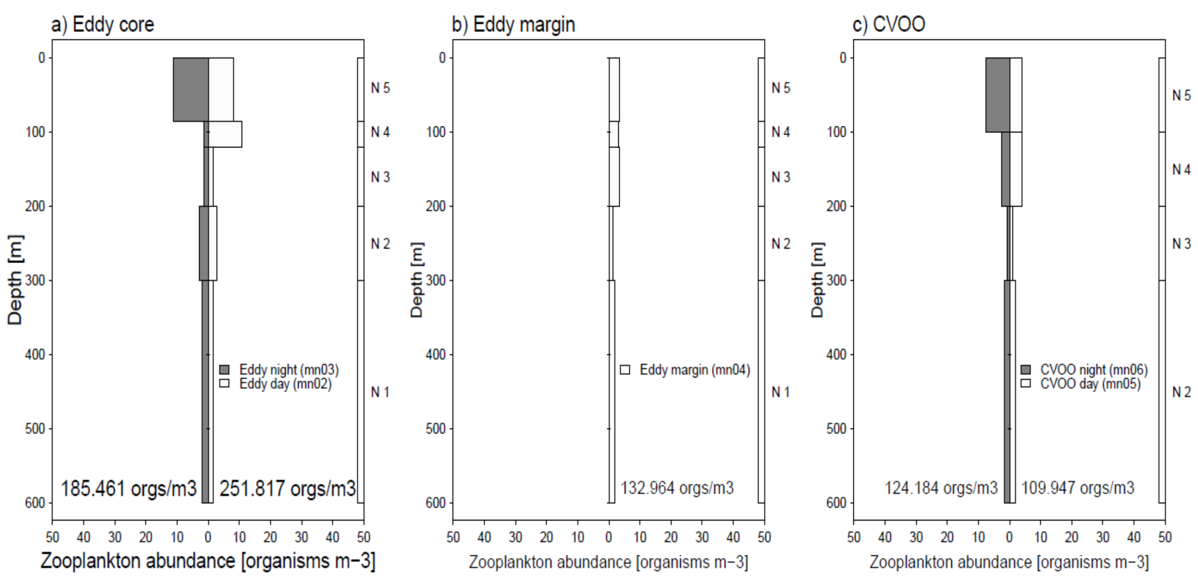

Figure 15: Abundance of Copepod *Oncaeaid* in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

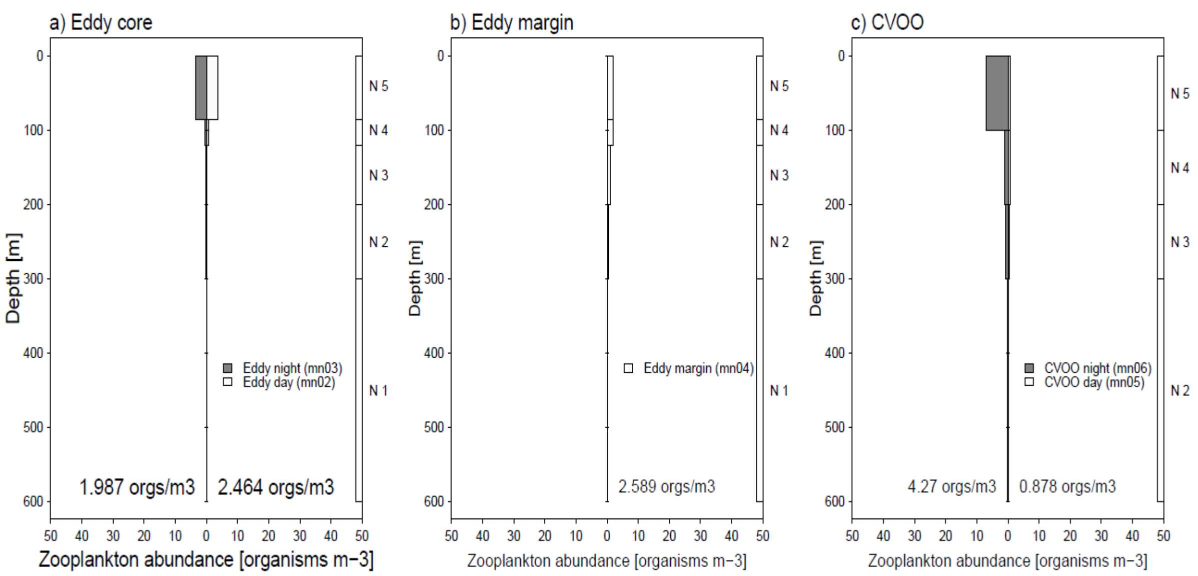

Figure 16: Abundance of crustacean Euphausiid in the core and in the margin the eddy and CVOO observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, in mid of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

The Ostracod (Figure 17) were more abundant of 100 to 150 m depth, with about 30 organisms/m3 at the core of the Eddy, during the day and 40 organisms/m^3 in the margin of 100 to 300 m depth. During the day, identified greater abundance of Chaetognath (Figure 18) in the core than in the margin the eddy.

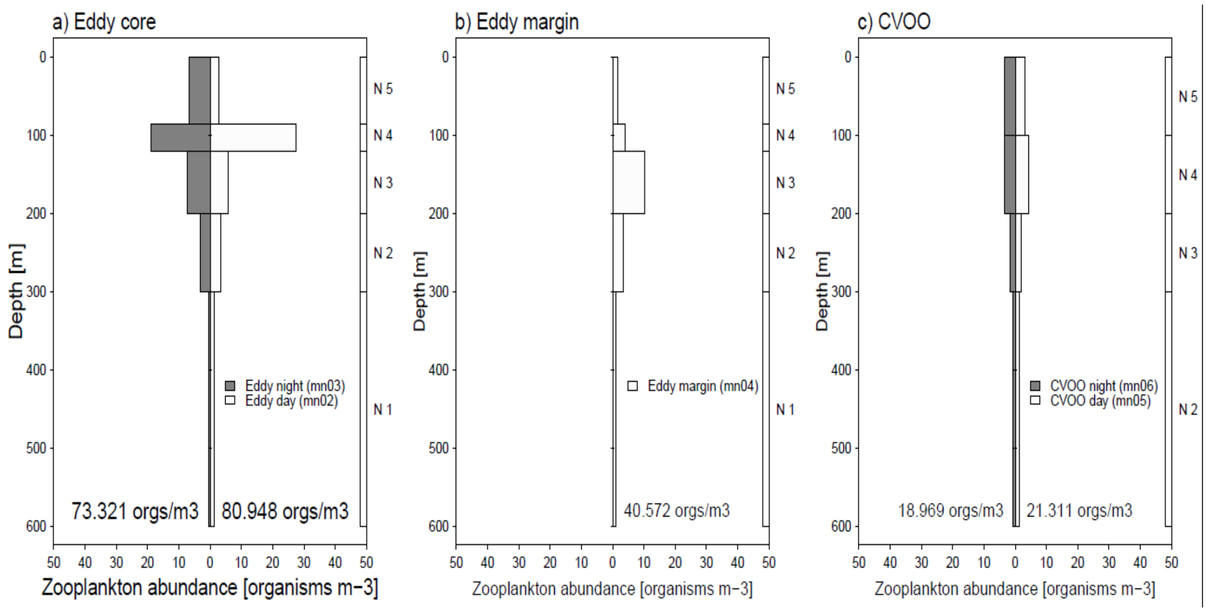

Figure 17: Abundance of crustacean Ostracod in the core and in the margin the eddy and CVOO observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, during the month of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

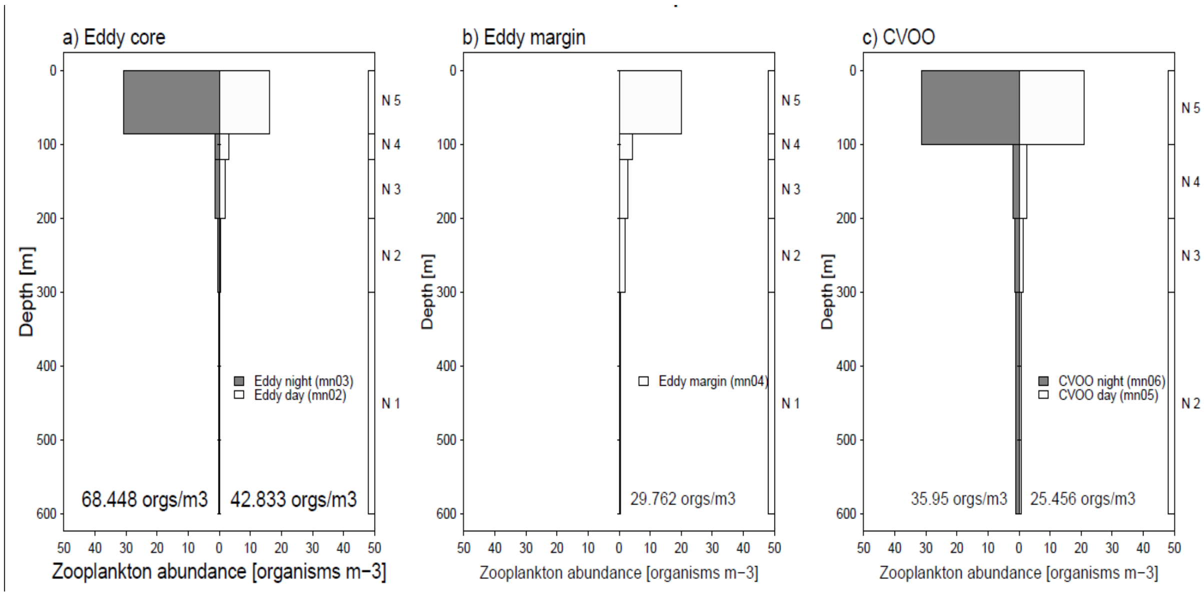

Figure 18: Abundance of Chaetognath in the core and in the margin the eddy and CVOO Observatory, up to 600 m of depth, during the day and also at night, sampled by the vessel Meteor, during the month of March 2014. Drawn up in accordance with the program R (R Core Team, 2014).

The samples collected with the UVP showed that at the core of the Eddy, more precisely in the OMZ, the peak of individuals found was about 150 particles per litre in the first 100 m and in the margin was about 130 particles/L at the surface, reducing to values around 100 particles/L under 20 m (Figure 19). Furthermore, it should emphasize that the abundance of particles fluctuated as the depth increases.

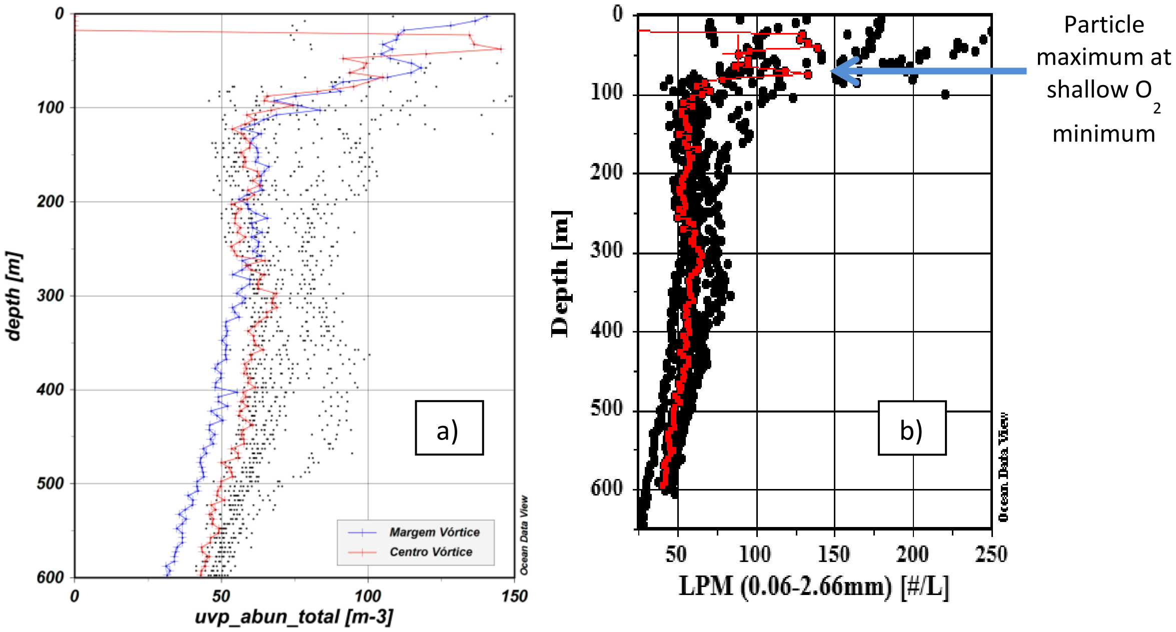

Figure 19: Vertical profile of the abundance of particles in the nucleus and in the margin the Eddy, up to 600 m depth sampled by ship Meteor in mid of March 2014. a) abundance of particles in the nucleus and in the margin the Eddy, b) abundance of particles with size between 0 0.06 to 2, 66 mm per litre. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013).

The data provided the UVP confirmed the results obtained the MultiNet, although the UVP represented the abundance of particles present in the water column and not only of zooplankton (Figure 20). From these data teamed the particles by size order, in which it was obtained a high concentration of particles in more superficial layers, to about 100 m depth, corroborating with the results obtained in sampling with MultiNet. However, the results showed that there is a large concentration of particles (100 particles) in the area where the oxygen is minimal (under 85 m depth, see Figure 21).

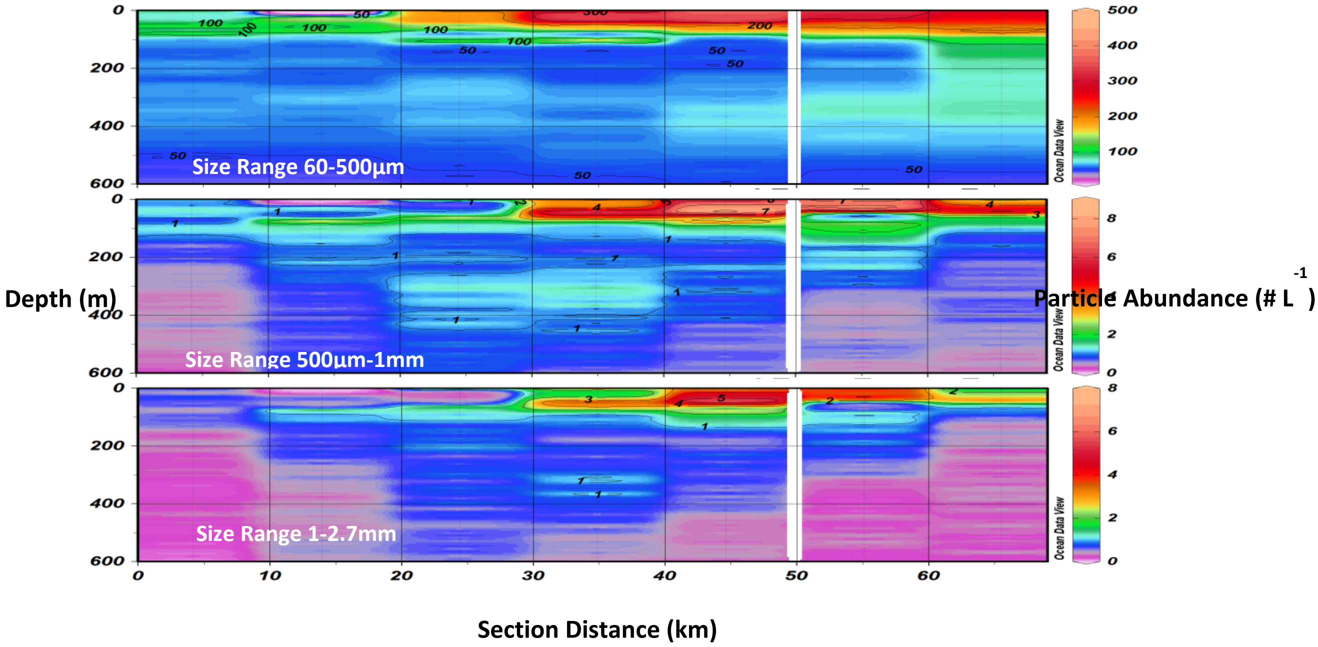

Figure 20: Section of the abundance of particles in the eddy, up to 600 m of depth sampled by the vessel Meteor, during the month of March 2014. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013).

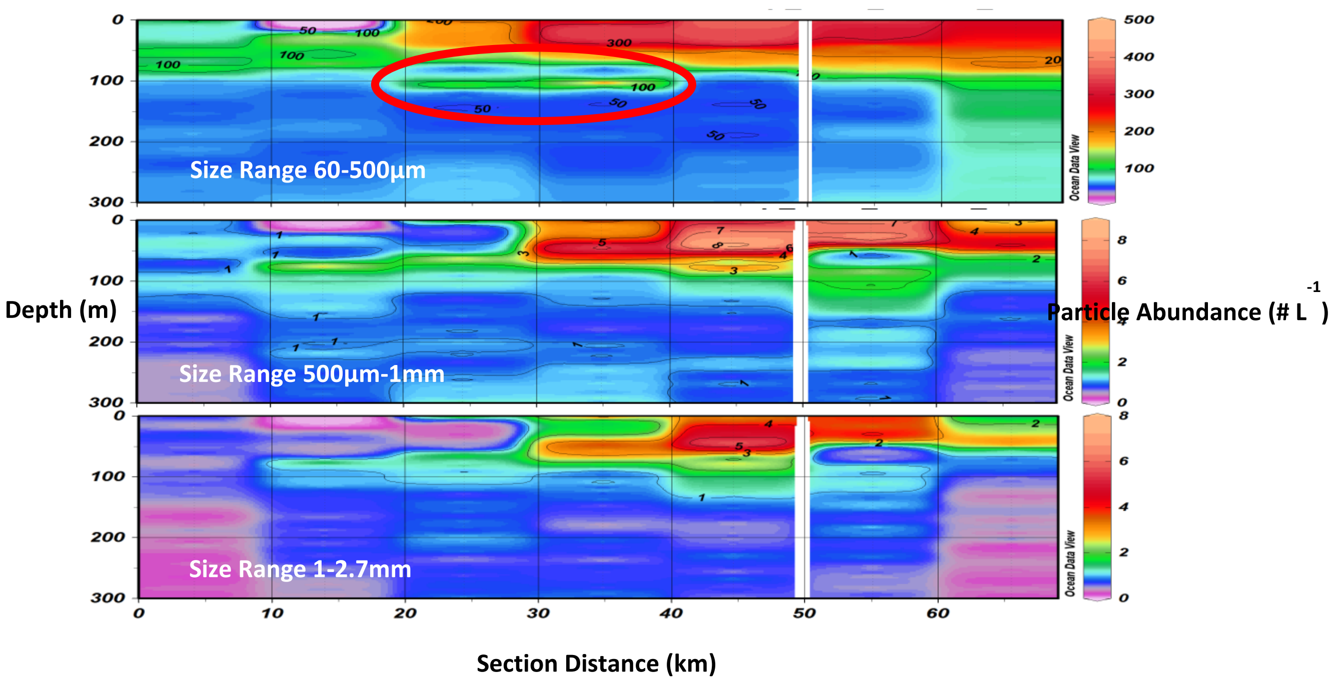

Figure 21: Section of the abundance of particles in the eddy, up to 600 m of depth sampled by the vessel Meteor, during the month of March 2014. Drawn up in accordance with the program Ocean Data View (Schlitzer, 2013).

5- Discussion

5.1- Physico-chemical properties in the Eddy

Zooplankton represent an important link in the pelagic food web of the marine ecosystem, therefore, changes in their abundance and composition can cause profound changes in all trophic levels (Rodrigues, V. H., 2012).

Eddies are oceanic structures that may lead to modifications in the composition of this community once carrya wide variety of chemical and biological properties, different from the external environment and can be incompatible the survival of some species and beneficial for other (Schütte, 2013).

The analysis of the obtained results showed that the thermocline and halocline were more superficial in the Eddy core in relation to the margin and the CVOO. The gradients were more pronounced towards the nucleus, which revealed a shallower mixing layer in the core of the eddy, possibly due to weak winds, precipitations and increased cloudiness (Skielka, 2009). This is important because it leads to higher concentrations of nutrients in the euphotic zone and increased growth of phytoplankton, triggering greater oceanic productivity.

For Schütte (2013) concentrations of oxygen in a eddy have a uniform vertical distribution normal, around 100 m depth, in which decreases in the concentrations observed in the mixing layer. Differences in temperature and salinity found in three sampled stations were minimal, which means these properties remained almost unchanged in the eddy.

The fact that the phytoplankton use chlorophyll to synthesize molecules of O_2 and glucose in the photosynthetic process, the chlorophyll content is used as index of biomass of phytoplankton (Franco, 2007).

Chlorophyll absorbs visible radiation of sunlight providing to photosynthetic organisms the energy required to synthesize organic products essential to the development of their vital activities (Franco, 2007). Being chlorophyll affected by turbidity of the water, this can be one of the reasons why their maximum concentration has been found around the 100 m depth, layer where greater penetration of visible light radiation. In this way, the phytoplankton remains only on the surface to benefit from sunlight which focuses on Ocean layers. The concentration of chlorophyll found in the Centre of the eddy was superior to that found on the shore and at the Observatory. One of the reasons for this is the fact that there are no upwelling of nutrients (which is the profile found in the CVOO) in the open ocean and therefore the concentration of chlorophyll is very low on the surface and in depth due to nutrient limitation. However in the eddy no limitation of nutrients and productivity was high, so the chlorophyll concentration was greater in surface.

The values of oxygen found in the centre of the eddy were high (about 230 µmol/kg) until the 80 m depth, where the photosynthetic activity and the atmospheric diffusion lead to breakthrough, but below that depth values decreased dramatically reaching values less than 10 µmol. Kg^{-1} of 85 to 120 m depth. This is an atypical scenario for the Eastern Tropical North Atlantic, which features a permanent minimum oxygen between 300 to 600 m depth, although hardly registers values below 40 µmol. Kg^{-1} (Karstensen *et al*., 2008), according to the results presented in the CVOO. This may be due to the fact that the eddy is a closed ecosystem and the oxygen trapped in it gets consumed by biological processes and it can also be due to climate change, which have caused a decrease in the oxygen level of the oceans (Stramma *et al*., 2008; Fiedler, s.d.).

The results of samples of nutrients show that the concentration of nutrients in the eddy has increased over time and that she was higher inside the eddy than outside this. Also could see that in the area where the oxygen was minimal nutrient concentration was higher. The reason for this may be that the eddy has been generated in a coastal upwelling zone, where the abundant water mass is the SACW, which is a mass of water of low salinity, colder, with low oxygen content, rich in nutrients and reaches about 600 m depth in the tropical Atlantic (Stramma *et al*., 2008; Schütte, 2013). The eddy then would have loaded this water captured at its core to the North of the Cape Verde Islands, where the predominant water mass is the NACW (Schütte, 2013).

In regions where oxygen concentrations are low (less than 10 µmol/kg), nitrate present in the water is a result of the respiratory process (Stramma *et al*., 2008). According to the results, increased nitrate concentrations at about 85 m deepth and had a slight decrease after the 100 m depth, probably this was the depth interval where nitrite (nitrite values decrease in the same depth interval) is converted to nitrate.

5.2- Abundance of Zooplankton

Hypoxia conditions entail various impacts on the marine ecosystem, causing the death of several important organisms (Stramma *et al*., 2008), as is the case of zooplankton. These are heavily influenced by the presence of dissolved oxygen in seawater, concentration of nutrients available, phytoplankton density, time of day, among other (CETESB, 2000; Yebra, 2001).

The concentration of zooplankton obtained using the two methods showed a higher abundance of zooplankton in the core of the eddy than in this margin, whicis is because the translational speed (0.04 m/s) of the eddy was much smaller than its rotation speed (0.7 m/s), which prevents the surrounding water to influence the water in the Centre of the eddy (Schütte, 2013), becoming the organisms restricted in the Centre of the eddy.

The results concerning the total abundance of zooplankton in the core of the eddy, observed in this study were very similar to those found by Gomez (1991) and Yebra (2001), both held in the Canary Islands.

A curious case is that found greater abundance of zooplankton in the core of the eddy than in the CVOO Observatory, however there has been greater abundance in this than in the margin the eddy, both day and night, maybe because the conditions are better in the eddy than in the Observatory (Yebra, 2001). The results demonstrated that within the eddy the concentration of nutrients and phytoplankton surface productivity are larger and the values of temperature and salinity are favorable, suitable conditions for proper growth and reproduction of zooplankton (Clark *et al*, 2001). As has been said, the motion of rotation caused the organisms to focus more on the core. The results suggest that the CVOO also had a proper environment survival of zooplankton, which led him to have more bodies than in the margin the eddy.

Also it should be noted that at night the concentration of zooplankton in the surface was higher than during the day, which shows that many of the zooplânctones held daily vertical migration.

According to the results obtained, the most abundant group was the copepods Calanoid, which includes a wider range of species, because they are dominant in biomass, closely related to the local hydrological properties (Hernandéz-León, 1988). The Euphausiid were the least plentiful because they are very large animals, which are commonly less abundant that small copepods, because they are more likely to be caught by predators, who use the vision for hunting (Menezes, 2007).

By the results, it became clear that the Euphausiid were the most sensitive to low oxygen content because they bypassed that zone throughout the day, since they did not diurnal vertical migrations, remaining above the oxygen minimum zone.

One could clearly see that there are greater abundance of zooplankton from the surface to 100 m depth, where the oxygen content is maximum (up to approximately 85 m), however it was observed a certain tolerance of hypoxia. Below this depth, oxygen levels have decreased considerably and the abundance of zooplankton was also very low, a exception was groups like the Macrosetella, *Oncaeaid*, Ostracod and Eucalanid, that had a higher abundance of organisms under 100 m depth (zone of low oxygen content).

According to Flint *et al*. (1991) the Eucalanid are organisms with low metabolism, allowing them to survive for a long time in layers with very low oxygen content, characterizing them as typical animals of oxygen minimum zones, as described in the results.

Second Green & Dagg (1996) the *Oncaeaid*, Macrosetella, Ostracod are organisms that tend to form aggregates, which leads them to sink more easily.

The results obtained in this study show that the impacts on the marine ecosystem of the eddies can be both positive and negative, since many species do not survive the low oxygen content and other can adapt to him due to their low metabolism.

6- Final Considerations

Recently many scientists have focused their interest on the role of eddies on marine ecosystems, notwithstanding such studies were not found in Cabo Verde, moreover, studies on the effect of eddies in the biological community have never been conducted in Cabo Verde.

The results reported in this study provide the first data on the effect of eddies in zooplankton community of Cabo Verde, serving as a basis for future studies with special emphasis on the impact that this has on management of fisheries resources.

With this work the presence of an oxygen minimum zone (OMZ) in an anticyclonic eddy northeast of the Cabo Verde archipelago was documented.

Some groups, such as the Eucalanid, have benefited from the oxygen minimum zone shallow, because it managed to resist hypoxia, due to their low metabolism. Other groups such as the Euphausiid a prevented the oxygen minimum zone, safeguarding their survival.

It might also be noted that the eddy studied, possessed excellent conditions for the survival of species of zooplankton, but only up to 85 m depth, however, there is a need to better assess the data recorded by UVP for groups of zooplankton, in order to consolidate the results presented in this study.

Ideal conditions were due to the fact the eddy had loaded into its core waters from the SACW, which is a mass of water with strong upwelling and thus high nutrients concentration.

Below this depth until 100 m the oxygen minimum zone was found, where the abundance of some taxon of zooplankton was low mainly due to hypoxia.

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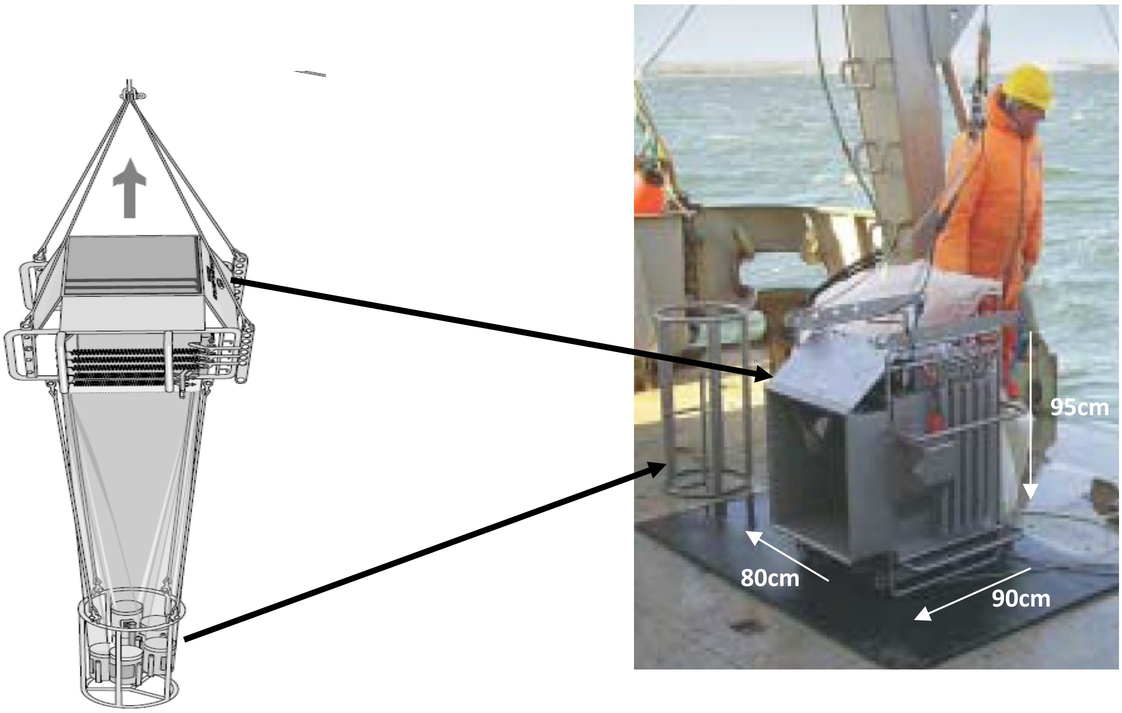
8- Attachments

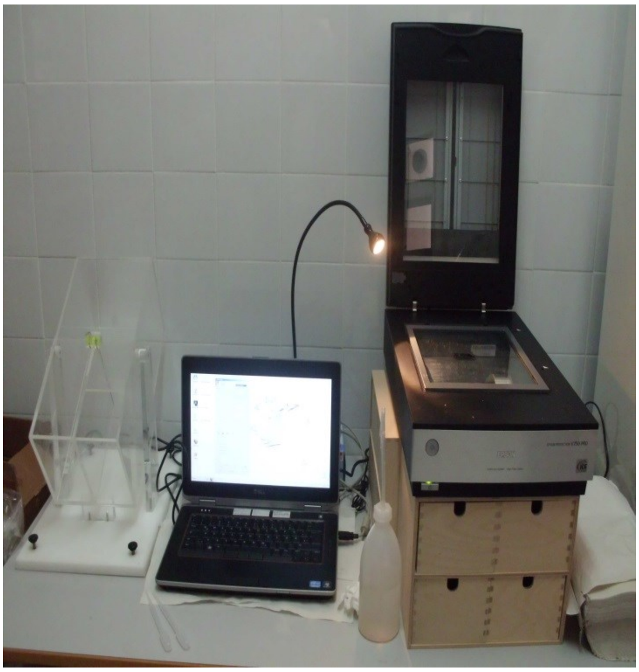
Annex A

Ship Islandia of INDP and ship Meteor of Geomar, from: Vieira (2010)

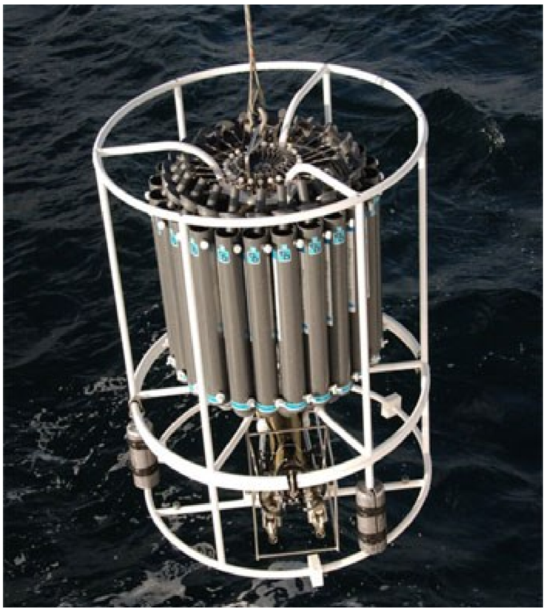


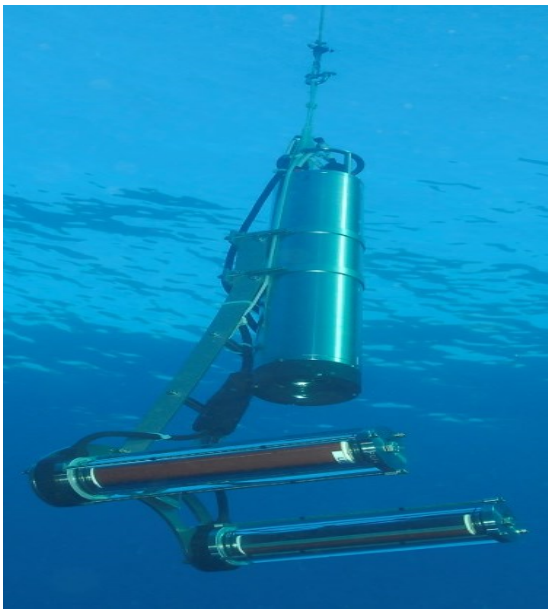
Multi net sampler (multinet), device used to collect zooplankton at different depths, previously defined. From: Hydrobios. (s.d.)

Annex B



Scanner for scanning of zooplankton and automatic Analyzer for determination of dissolved nutrients in each sample. From: own source e Rodrigues, E. (2012), respectively.





CTD used for sampling of dissolved oxygen and nutientes. UVP used in collecting photographs of zooplankton in the water column. From: NOAA Okeanos Explorer Program (2010) e Luquet (2013), respectively.

Annex C

Multinet Midi Station Log

Station ID		
Haul #		
Lat (xx°xx.xx'N/S)		
Lon (xxx°xx.xx'W/E)		
Date (yyyy/mm/dd)		
Time start		□UTC
Time end		□local

Ship	
Operator	

Cloud cover (0/8-8/8)	
Wind speed (m/s)	
Wind direction (°)	
Swell (m)	

max. cable length (m)	
Data file name	

		from data file		
Sample	Set Pressure range (dbar)	Depths OK?	Filtered volume (m^3)	Remarks
Net 1				
Net 2				
Net 3				
Net 4				
Net 5				

Completed Protocol on Board at the time of collection of samples from zooplacton using the multinet.

Annex D

Scan Protocol Zooplankton SFB754-B8

Scan Date	
Sampler initials	

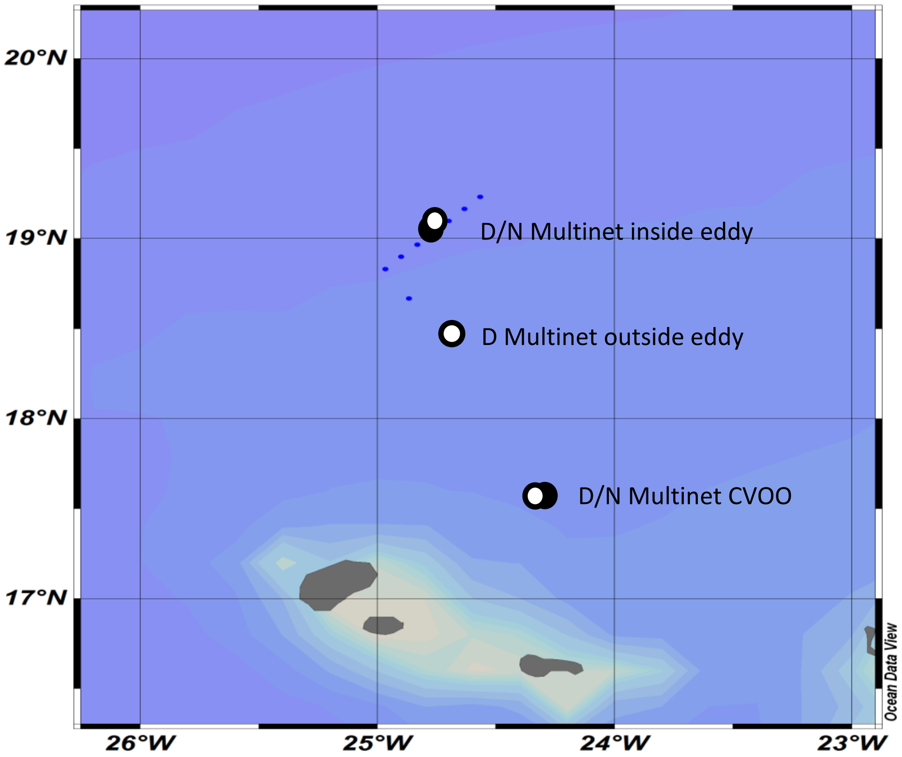
lrg > 1000µm
med 500-1000µm
sml 200-500µm

a	
b	

Cruise ID	Haul #	Net #	Size fraction	Split ratio	# of split	File name	remarks	Sample still quantitative & OK?

Completed in the laboratory Protocol to perform scanning of the zooplankton samples collected by multinet.

Annex E



Map of location of Multinet released inside and outside the eddy and CVOO, day (D) or night (N).

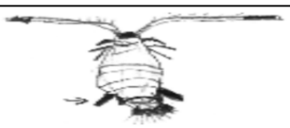
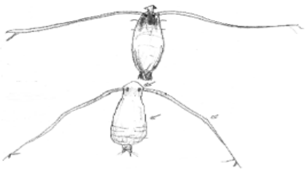
category	sort into this category when you see the following characteristics	exemplary image
art_bubble	roundish; great variation from light to dark; no spots	
art_dupl	object is already on another (better) image	
art_glue	used to belong to grey-filters	
art_line	drawn lines from scan-chamber; straight line	
art_scratch		
cop_calanid	long, slender antennulae; body-shape: long, without spines	
cop_candaciid	long antennulae; compact body lightly coloured; spiny last thoracal segment; dark (hind) legs; caudal setae same length	
cop_coryceid	very short antennulae, ocular lenses in front part of head, first of urosomal somites thickened, caudal rami with two long caudal setae	
cop_eucalanid	very long antennulae on sides of head; body-shape: long, slender; "nose"/"anchor"; short urosome	

Table for the classification of zooplankton taxa, from Christiansen (2013)

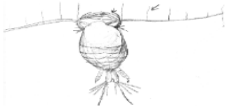
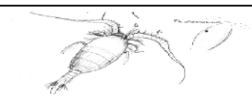
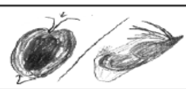
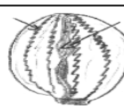
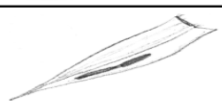
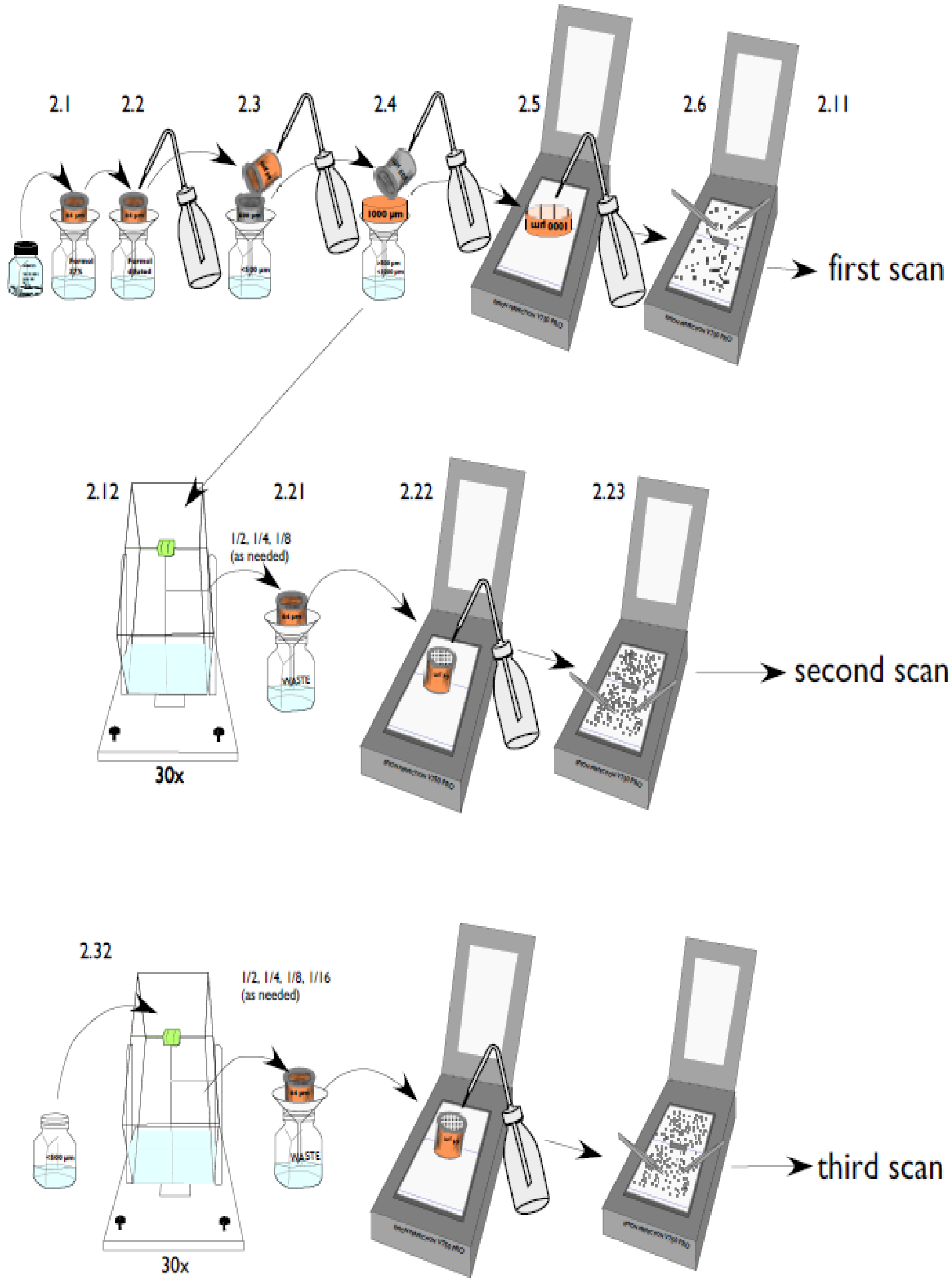
category	sort into this category when you see the following characteristics	exemplary image
cop_euchaetidae	antennulae with long setae, large maxillipeds as "cage", "extended away from anterior section of body" (1)	
cop_macrosetella	very short first antennulae; body-shape: slender, slightly bent; very long, single caudal seta	
cop_metridinid	antennulae long and swung, with short setae on somites; legs and maxillipeds hairy; Pleuromamma with black point on side	
cop_miracia	very short antennulae; body bent; hind legs directing to urosome	
cop_oithonid	body slender; very long urosome	
cop_oncaeid	short antennulae; body-shape: compact and roundish; urosome may be thickened	
cop_other	copepods you can not identify or that do not fit into any of the cop_-categories (eg. Nauplius-larvae); 2 Antennulae, body-shape, urosome, naupliid-eyes	
cop_other lateralview	copepods you can not identify that are lying on their side	
cop_paracalanid	do not sort into this category; too hard to distinguish with this method	
crust_amphipod	dorso_ventrally flattened body; paired or fused compound-eyes; no carapax; body bent, mostly in lateral-view (Lowry, 1999 onwards, access date: 5th July 2013)	
crust_clado		
crust_euphausiid	decapod; slender body; short legs; gills visible between thoracopods and pleopods	
crust_ostracod	two visible valves (like mussle-shells), two antennae visible	
det_aggregate	particles that have clearly not been anything living	
det_darkparticle	very dark particles with distinct edges	
det_feces_like		
det_fiber	fibers that did not belong to any organism; without hairs or setae	
egg	round object with nucleus or embryo inside	
fish	two eyes; fins visible; somites	
gel_carn_chaetognath	long, slender body; head with hooks; caudal fin visible	
gel_carn_ctenophora	comb-rows visible; gut complete	
gel_carn_medusa	umbrella without comb-rows; gut not reaching posterior section; sometimes tentacles	
gel_carn_siphonophore	body pointed; gut visible; often copepods inside	

Table for the classification of zooplankton taxa, from Christiansen (2013)

Annex F



Preparation of the scaner and scan of zooplankton samples using the Zoo-scan method, from Christiansen (2013).